The Consultative Committee for Space Data Systems

Draft Recommendations for Space Data System Standards

RADIO FREQUENCY AND MODULATION SYSTEMS—

PART 1

DRAFT RECOMMENDED STANDARD

CCSDS 401.0-P

PINK SHEETS

December 2004

2.1.3B TRANSMITTER FREQUENCY SWEEP RANGE ON EARTH-TO-SPACE LINKS, CATEGORY B

The CCSDS,

considering

(a) that the Doppler frequency shift on the earth-to-space link, resulting from relative motion between earth stations and category B spacecraft, can achieve values up to:

± 250 kHz at 2 GHz
± 900 kHz at 7 GHz;
± 4 MHz at 34 GHz;

(b) that the rest frequency uncertainties in spacecraft receivers are on the order of:

± 1 kHz at 2 GHz
± 4 kHz at 7 GHz;
± 18 kHz at 34 GHz;

(c) that the Doppler frequency shift can usually be predicted to an accuracy of ± 1 kHz;

(d) that most of the spacecraft receivers have tracking ranges less than or equal to:

± 300 kHz at 2 GHz
± 1 MHz at 7 GHz;
± 4 MHz at 34 GHz;

(e) that the lock-in frequency range of spacecraft receivers is much smaller than the frequency deviations given in (a) and (b) above;

(f) that the effect on the radio link, resulting from variation in the columnar charged-particle content, is generally negligible;

(g) that the acquisition time should be kept to a minimum;

recommends

that the earth station's transmitter should have a minimum sweep range capability of:

± 1 kHz at 2, ~~and~~ 7, and 34 GHz

and a maximum sweep range capability of at least:

± 300 kHz at 2 GHz
± 1 MHz at 7 GHz.
± 4 MHz at 34 GHz.

2.1.4B TRANSMITTER FREQUENCY SWEEP RATE ON EARTH-TO-SPACE LINKS, CATEGORY B

The CCSDS,

considering

(a) that the rate of change of the Doppler frequency shift on the earth-to-space link, resulting from relative motion between earth stations and category B spacecraft, is smaller than:

~~60~~70 Hz/s at 2 GHz
~~200~~240 Hz/s at 7 GHz;
1200 Hz/s at 34 GHz;

(b) that most of the spacecraft receivers have a phase-locked loop with a bandwidth ($2 B_{LO}$) in the range 10 Hz to 100 Hz at their threshold;

(c) that the maximum permissible rate of input frequency variation for this type of spacecraft receiver is between 6 Hz/s and 1 kHz/s at its threshold;

(d) that the maximum permissible rate of input frequency variation for signals above the receiver's threshold can be as much as 10 kHz/s;

(e) that the frequency sweep rate on the earth-to-space link should be chosen such that the total rate of frequency variation, resulting from both the transmitter's sweep rate and the orbital Doppler rate, does not unlock the spacecraft's phase-locked loop;

(f) that the acquisition time should be kept to a minimum for each mission phase;

recommends

that the earth station's transmitter should have a minimum frequency sweep rate capability of:

1 Hz/s

and a maximum frequency sweep rate capability of at least:

10 kHz/s.

2.1.7B OPERATIONAL AND EQUIPMENT CONSTRAINTS RESULTING FROM SIMULTANEOUS TELECOMMAND AND RANGING IN RESIDUAL CARRIER SYSTEMS, CATEGORY B

The CCSDS,

considering

(a) that coherent transmissions are generally employed for making range measurements to a Category B mission spacecraft;

(b) that conventional phase locked loop receivers require a residual carrier component to operate properly;

(c) that sufficient power must be reserved to the residual carrier so that the spacecraft receiver can track with an acceptable phase jitter;

(d) that sufficient power must be allocated to the command data channel to obtain the required bit error rate;

(e) that in two-way operation, the noise contained in the transponder's ranging channel bandwidth will be retransmitted to the earth station along with the ranging signal;

(f) that sufficient power must be allocated to the ranging signal to obtain the required accuracy and probability of error;

(g) that some ranging systems permit the simultaneous transmission of several tone frequencies from the earth station and that a proper choice of these frequencies will minimize the cross-modulation and interference to the telecommand signal by the ranging signal;

(h) that transmission of a single, low frequency ranging tone by the earth station may result in interference in the telecommand channel on the spacecraft;

recommends

(1) that the telecommand modulation index shall not be less than 0.2 radians peak;

~~(2) that the telecommand data bit rate shall not exceed 2000 b/s when simultaneous telecommand and ranging operations are required;~~

(~~3~~2) that the earth station's ranging modulation index shall not exceed 1.4 radians peak;

(~~4~~3) that the telecommand subcarrier's period should be an integer subdivision of the data bits' period;

~~(5) that for those ranging systems which do not conform with *recommends (6)* below, the telecommand subcarrier's period should be a coherent multiple of the ranging tone's period;~~

(~~6~~4) that, where necessary, each and every lower frequency ranging tone be chopped (modulo-2 added) with the highest frequency ranging tone.

2.3.2 USE OF SUPPRESSED CARRIER~~S~~ MODULATIONS (BPSK/QPSK) FOR ~~HIGH~~MEDIUM-RATE ~~TELEMETRY,~~ SPACE-TO-EARTH LINKS

The CCSDS,

considering

(a) that present technology makes the implementation of suppressed carrier modulation systems practicable;

(b) that a comparison of carrier signal-to-noise ratios in a conventional residual carrier phase-locked loop with those in a suppressed carrier loop shows that the latter provides a substantial advantage over the former, frequently exceeding 10 dB;

(c) that a comparison of data symbol errors occurring in a conventional residual carrier phase-locked loop system with those occurring in a suppressed carrier loop system shows that the latter's performance is no worse, and frequently is better, than that of the former;

(d) that suppressed carrier systems lend themselves to compliance with PFD limits on the Earth's surface more readily than do residual carrier systems;

~~(e) that some space agencies still use autotrack systems for their Category A missions, which need a residual carrier;~~

(e) that Recommendation 2.4.17A defines recommended bandwidth-efficient modulation formats for high symbol rate (> 2 Msps) space-to-Earth transmissions from Category A missions in space research service bands;

(f) that Recommendation 2.4.17B defines recommended bandwidth-efficient modulation formats for high symbol rate (> 2 Msps) space-to-Earth transmissions from Category B missions in space research service bands;

(g) that Recommendation 2.4.18 defines recommended bandwidth-efficient modulation formats for high symbol rate (> 2 Msps) space-to-Earth transmissions from missions in Earth exploration-satellite service;

(h) that short periodic data patterns can result in zero power at the carrier frequency;

recommends

(1) that CCSDS agencies utilize suppressed carrier ~~systems~~ modulation formats such as BPSK, QPSK, or OQPSK[1,2] for medium rate (≤ 2 Msps) space-to-Earth communications whenever possible and in any case when a residual carrier system would exceed the PFD limits on the Earth's surface;

~~(2) that CCSDS agencies may provide a beacon for autotracking their Category A missions using suppressed carrier modulation.~~

[1] Subject to the constraints of SFCG recommendations 21-2R1 and 23-1 or latest version.
[2] See also recommendation CCSDS 401.0 (3.3.3A) B-2.

(2) that CCSDS agencies refer to Recommendations 2.4.17A, 2.4.17B, and 2.4.18 for recommended modulation formats for high symbol rate (> 2 Msps) transmissions;

(3) that CCSDS agencies use a data randomizer as specified in CCSDS 131.0-B-1, *TM Synchronization and Channel Coding* (Blue Book, Issue 1, September 2003 or latest issue).

2.3.3A EARTH STATION RECEIVER ACQUISITION FREQUENCY ~~SWEEP~~ RANGE, CATEGORY A

The CCSDS,

considering

(a) that the space-to-earth link may be operated in either a coherent turnaround mode, or in a one-way mode;

(b) that for the coherent turnaround mode, the Doppler frequency shift induced on both the earth-to-space and the space-to-earth links is the major factor to be considered in selecting the frequency ~~sweep~~acquisition range;

(c) that for the one-way mode, both the Doppler frequency shift induced on the space-to-earth link and the frequency stability of the spacecraft's oscillator are the major factors to be considered in selecting the frequency ~~sweep~~acquisition range;

(d) that the maximum rate of change of distance between the earth station and Category A spacecraft can reach values of up to 10 km/s;

(e) that the minimum frequency stability found in Category A spacecraft reference frequency oscillators is about 2×10^{-5} = 20 ppm;

(f) that the Doppler frequency shift can usually be predicted to an accuracy of ± 1 kHz;

(g) that digital receivers can use FFT algorithms for carrier acquisition rather than frequency sweeping;

recommends

(1) that CCSDS agencies' earth station receivers be capable of frequency ~~sweep~~acquisition ranges of at least:

± 150 kHz at 2 GHz[1]
± 600 kHz at 8 GHz[1]
± 1800 kHz at 26 GHz[1]

(2) that CCSDS agencies provide a minimum ~~sweep~~acquisition range that is consistent with their ability to predict the Doppler frequency shift.

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[1] These numbers cover the worst case between two-way and one-way modes with spacecraft oscillator stability included in the latter.

2.3.3B EARTH STATION RECEIVER ACQUISITION FREQUENCY ~~SWEEP~~ RANGE, CATEGORY B

The CCSDS,

considering

(a) that the space-to-earth link may be operated in either a coherent turnaround mode, or in a one-way mode;

(b) that in the coherent turnaround mode, the Doppler frequency shift induced on both the earth-to-space and the space-to-earth links is the major factor to be considered in selecting the frequency ~~sweep~~acquisition range;

(c) that the effect on the radio link, resulting from variation in the columnar charged-particle content, is generally negligible;

(d) that the maximum rate of change of distance between the earth station and Category B spacecraft can reach values of up to 35 km/s;

(e) that the minimum frequency stability found in Category B spacecraft reference frequency oscillators is about 1×10^{-6} = 1 ppm;

(f) that the Doppler frequency shift can usually be predicted to an accuracy of ± 1 kHz;

(g) that digital receivers can use FFT algorithms for carrier acquisition rather than frequency sweeping;

recommends

(1) that CCSDS agencies' earth station receivers be ~~capable of~~able to support frequency ~~sweep~~acquisition ranges of at least:

± 300 kHz at 2 GHz[1]
± 1 MHz at 8 GHz[1].
± 4 MHz at 32 GHz[1]

(2) that CCSDS agencies provide a minimum acquisition range that is consistent with their ability to predict the Doppler frequency shift.

[1] Maximum acquisition range applies to one-way (non-coherent) mode; coherent turnaround mode will approximately double maximum acquisition range.

2.3.4A EARTH STATION RECEIVER ACQUISITION FREQUENCY SWEEP RATE, CATEGORY A

The CCSDS,

considering

(a) that the space-to-earth link may be operated in either a coherent turn-around mode or in a one-way mode;

(b) that in the coherent turn-around mode, the Doppler frequency rates induced on both the earth-to-space and the space-to-earth links are the major factors to be considered in selecting the earth station receiver's frequency sweep rate;

(c) that in the one-way mode, the Doppler frequency rate on the space-to-earth link and the earth station receiver's phase locked loop bandwidth (2 B_{LO}), with its resulting maximum permissible input frequency variation, are the major factors to be considered in selecting the sweep rate;

(d) that the rate-of-change of velocity[1] between the earth station and Category A spacecraft can reach values up to 380 m/s^2 ~~at orbital altitudes of 300 km~~, which results in frequency variation rates of approximately 3 kHz/s at 2 GHz, ~~and~~ 10 kHz/s at 8 GHz, and 34 kHz/s at 26 GHz in the one-way mode (or 6 kHz/s, ~~and~~ 20 kHz/s, and 68 kHz/s respectively in the coherent turn-around mode);

(e) that the earth station's receivers generally have phase locked loop bandwidths (2 B_{LO}) in the range of 30 Hz to 2 kHz at their threshold;

(f) that, for an acquisition probability of 0.9, the maximum permissible rate of input frequency variation for this type of earth station receiver is between 100 Hz/s and 400 kHz/s at its threshold;

(g) that the earth station receiver's frequency sweep rate plus the spacecraft's Doppler frequency rate must not exceed the receiver's ability to achieve phase-locked operation;

(h) that the acquisition time should be kept to a minimum for each mission phase;

recommends

that CCSDS agencies' earth station receivers operating in the 2, ~~and~~ 8, and 26 GHz bands should have a minimum frequency sweep rate not exceeding 100 Hz/s and a maximum frequency sweep rate of at least ~~420~~200 kHz/s.

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[1] For circular orbits the Doppler rate is negative.

2.3.4B EARTH STATION RECEIVER ACQUISITION FREQUENCY SWEEP RATE, CATEGORY B

The CCSDS,

considering

(a) that the space-to-earth link may be operated in either a coherent turnaround mode, or in a one-way mode;

(b) that in the coherent turnaround mode, the Doppler frequency rates induced on both the earth-to-space and the space-to-earth links are the major factors to be considered in selecting the earth station receiver's frequency sweep rate;

(c) that in the one-way mode, the Doppler rate on the space-to-earth link and the earth station receiver's phase-locked loop bandwidth (2 B_{LO}), with its resulting maximum permissible input frequency variation, are the major factors to be considered in selecting the sweep rate;

(d) that the rate of change of velocity between the earth station and category B spacecraft can reach values up to 10 m/s^2;

(e) that the earth station's receivers have phase-locked loop bandwidths (2 B_{LO}) in the range of 1 Hz to 1 kHz at their thresholds;

(f) that typical earth station receivers, operating in the 2, ~~and~~ 8, and 32 GHz bands, allow a maximum permissible rate of input frequency variation of between 1 Hz/s and 10 kHz/s;

(g) that the receiver's frequency sweep rate, plus the orbital Doppler frequency rate, must not exceed the earth station receiver's ability to achieve phase-locked operation;

(h) that the acquisition time should be kept to a minimum for each mission phase;

(i) that a lower limit for the signal-to-noise ratio in the earth station receiver's phase-locked loop is approximately 8.5 dB;

recommends

that CCSDS agencies' earth station receivers, operating in the 2, ~~and~~ 8, and 32 GHz bands, should have a minimum sweep rate not exceeding 1 Hz/s and a maximum sweep rate of at least 10 kHz/s.

2.4.6 TELEMETRY SUBCARRIER [1] FREQUENCY STABILITY IN RESIDUAL CARRIER TELEMETRY SYSTEMS

The CCSDS,

considering

(a) that the present use of subcarriers[1] for modulating the space-to-earth RF links as in CCSDS Recommendation 2.4.7 represents a mature technique for both Categories A and B missions and, therefore, is a well settled standard;

~~(b) that modifications of this standard imply costly changes to space agencies' networks;~~

(~~c~~b) that the subcarrier[1] frequency-to-symbol rate ratio is an integer value as in CCSDS Recommendations 2.4.14A and 2.4.14B;

(c) that transponders can derive the subcarrier frequency from an oscillator or a NCO, if using digital processing;

(d) that the resolution of the subcarrier frequency NCO, if used, determines the subcarrier frequency settability and may be as large as 1 Hz;

(e) that the short term subcarrier frequency stability should be less than the ground station receiver subcarrier tracking loop bandwidth;

(f) that ground station receivers can have subcarrier tracking loop bandwidths as low as 100 MHz using digital processing;

(g) that the minimum long-term frequency stability found in Category A spacecraft reference-frequency oscillators is about ±20 ppm[1];

(h) that the minimum long-term frequency stability found in Category B spacecraft reference-frequency oscillators is about ±1 ppm;

recommends

that spacecraft radio frequency subsystems generating telemetry subcarriers be designed with characteristics equal to or better than:

Maximum Subcarrier[1] Frequency Offset[4]	$\pm$ (~~1~~2 × 10^{-4})f_{sc}
Minimum Subcarrier[1] Frequency Stability (short term)	$\pm 1 \times 10^{-6}$
Minimum Subcarrier[1] Frequency Stability (long term)	$\pm$ ~~1~~2 × 10^{-5}

NOTES:

1 For the purpose of this recommendation, subcarrier includes but is not limited to Bi-ϕ waveforms. In this case, the subcarrier-to-symbol rate ratio is one.

2. f_{sc} = frequency of telemetry subcarrier.

3. Short term time intervals are less than or equal, 100 times the subcarrier's waveform period.

4. For Category B missions with TCXO oscillators, the largest contribution is given by the number of quantization bits of the NCO. This is a deterministic offset that can be compensated for.

2.4.14B ALLOWABLE VALUES FOR TELEMETRY SUBCARRIER FREQUENCY-TO-SYMBOL RATE RATIOS FOR PCM/PSK/PM MODULATION IN THE 2 AND 8 GHz BANDS, CATEGORY B

The CCSDS,

considering

(a) that, for Category B missions, a PCM/PSK/PM modulation scheme with a squarewave subcarrier is typically used for transmission of low data rates;

(b) that integer subcarrier frequency-to-symbol rate ratios (n) result in a data spectral density minimum around the carrier frequency;

(c) that the subcarrier frequency-to-symbol rate ratio (n) should be minimized to avoid unnecessary occupation of the frequency spectrum;

(d) that the lowest practicable value of n can be determined by the amount of acceptable interference from the data spectrum (I) into the carrier tracking loop bandwidth (B_L);

(e) that, for Category B missions, a 0.1 dB degradation in the symbol detection process shall not be exceeded, which requires an 18 dB Carrier-to-Noise ratio (C/N) in the carrier tracking loop, when using CCSDS concatenated coding schemes;

(f) that any additional degradation, due to data interference in the carrier tracking loop, shall be insignificant for which a C/I ratio greater than 25 dB is considered adequate;

(g) that, for small ratios of symbol rate-to-carrier tracking loop bandwidth, the modulation index has to be adjusted accordingly in order to achieve the required loop SNR resulting in a nearly constant C/I versus B_L/R_S;

(h) that, in the presence of only one telemetry signal, a small value of n (n = 5) is generally sufficient to obtain the required performance under typical operating conditions for subcarrier frequencies above 60 kHz;

(i) that for higher symbol rates, the presence of telecommand feed-through and/or ranging signals may require the selection of a slightly higher value of n;

(j) that CCSDS Recommendation 2.4.3 provides guidance regarding the use of subcarriers in low bit rate residual carrier telemetry systems;

recommends

(1) that the subcarrier frequency-to-symbol rate ratio, n, be an integer value;

(2) that a subcarrier frequency-to-symbol rate ratio of 5 be selected for subcarrier frequencies above 60 kHz unless *recommends (3)* applies and that subcarrier frequencies do not exceed 300 kHz[1];

[1] See SFCG recommendation 23-1 or latest version.

(3) that, in the case of spectral overlaps with other signal components, the minimum integer value of n be selected to permit no more than a 0.1 dB degradation in the symbol detection process.

2.4.17B MODULATION METHODS AT HIGH SYMBOL RATES TRANSMISSIONS, SPACE RESEARCH, SPACE-TO-EARTH, CATEGORY B

The CCSDS,

considering

(a) that in accordance with ITU RR S3.9, efficient use of the RF spectrum resources is required;

~~(b) that the SFCG has approved a Recommendation[1] which specifies a spectral mask for emissions with symbol rates below and above 2 Ms/s in certain frequency bands;[2]~~

~~(c) that only filtered suppressed carrier systems meet the bandwidth efficiency requirements of SFCG spectrum mask Recommendation[1] for telemetry symbol rates in excess of 2 Ms/s;~~

~~(d) that GMSK[3] and, with proper trellis demodulation, T-OQPSK[4] modulations have negligible end-to-end losses while meeting the SFCG bandwidth requirements for symbol rates in excess of 2 Ms/s;~~

(b) that the SFCG has approved an Efficient Spectrum Utilization Recommendation[1] which specifies maximum allowable bandwidth (B25)[1] guidelines based on the symbol rate for emissions in the Space Research, Category B, 8 GHz band;

(c) that the maximum bandwidth (B25)[1] in the Space Research, Category B, 8 GHz band under the SFCG Recommendation[1] is limited to 12 MHz for non-Mars missions on a non-interfering basis to other missions and 8 MHz in all other cases;

(d) that the Space Research, Category B, frequency allocation at 2 GHz is 10 MHz, requiring high symbol rate users to share the band to be spectrally efficient;

(e) that 2 Ms/s is used as a boundary for the definition of high symbol rate for Space Research, Category A, Space-to-Earth transmissions in both the 2 and 8 GHz bands[2];

(f) that GMSK[3] is a spectrally efficient modulation with negligible end-to-end losses using an optimised receiver;

(g) that short periodic data patterns can result in zero power at the carrier frequency;

recommends

(1) that ~~either~~ GMSK[3] ~~or T-OQPSK[4]~~ be used for high data rate transmissions whenever practicable and in any case for rates in excess of 2 Ms/s in communications systems operating in either the 2 or 8 GHz bands, provided that in no case the transmission bandwidth (B25)[1] exceed that recommended by the SFCG[1];.

(2) that Category B missions requiring transmission bandwidths (B25)[1] higher than that recommended[4] by the SFCG in 8 GHz band use the 31.8-32.3 GHz band instead;

(3) that CCSDS agencies use a data randomizer as specified in CCSDS 131.0-B-1, *TM Synchronization and Channel Coding* (Blue Book, Issue 1, September 2003 or latest issue).

NOTES:

[1] See SFCG Recommendation ~~17-2R1~~23-1 or latest version.

~~[2] Category B bands are: 2290-2300 MHz and 8400-8450 MHz.~~

[2] See CCSDS Recommendation 401 (2.4.17A) B-1.

[3] Gaussian Minimum Shift Keying ($BT_B = 0.5$~~0~~), with precoding (see CCSDS 413.0-G-1).

~~[4] Trellis Offset Quadrature Phase Shift Keying; see CCSDS 413.0-G-1.~~

[4] Under the 12 MHz bandwidth limitation for non-Mars missions on a non-interfering basis, the maximum symbol rate using GMSK BT_B=0.5 is 9.3 Msps. For Mars missions and non-Mars missions which interfere with Mars missions, the maximum symbol rate using GMSK BT_B=0.5 is 6.2 Msps.

3.1.2B USE OF THE 8400 — 8450 MHz BAND FOR SPACE RESEARCH, CATEGORY B[1]

The CCSDS,

considering

(a) that the 8400–8450 MHz band is allocated for and restricted to Space Research service, Category B, missions;

(b) that users and data rates in the 8.4 GHz band continue to increase, and congestion in this band is more severe than in the 2 and 32 GHz bands;

(c) that spacecraft in the Mars region are much more vulnerable to mutual interference due to lack of spatial separation, and that a single unrestricted high-rate mission could occupy the entire 50 MHz allocation in the 8.4 GHz band, preventing its use by any other user in the Mars region;

(d) that five or six high-rate missions could conceivably coexist in the Mars vicinity in the future, making it necessary to limit the maximum allowable bandwidth for each mission to no more than 8 MHz in the 8.4 GHz band;

(e) that deep space missions designed for destinations other than Mars should also have restrictions on their maximum allowable bandwidths in the 8.4 GHz band, although at a less severe level since there is usually greater spatial separation between these missions;

(f) that separating two missions at the point where their power spectral densities are each 25 dB below their own spectral peaks is generally sufficient to prevent mutual interference;

(g) that an interference spectral power flux density of –266 dB(W/Hz/m^2) would, when received by a 70 meter antenna, be 16 dB below the noise floor of the receiving system and would raise the system temperature by only 0.1 dB;

recommends

(1) that, in the 8400-8450 MHz band, the maximum allowable bandwidth (B25)[1] of telemetry signals be limited according to Figure 3.1.2B-1[2], wherein

a) the lower curve applies to all missions;
b) a larger bandwidth (B25)[1] is available to the non–Mars missions as defined by the upper curve, strictly on condition that they would not interfere with the Mars missions;

(2) that, in the 8400-8450 MHz band, the spectral power flux density outside the maximum allowable bandwidth (B25)[1] be limited to –266 dB(W/Hz/m^2) on the surface of the Earth.

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[1] See SFCG Recommendation 23-1 or latest version.

[2] For the purpose of this Recommendation, the Symbol Rate (R_s) is defined in Figure 3.1.2B-2.

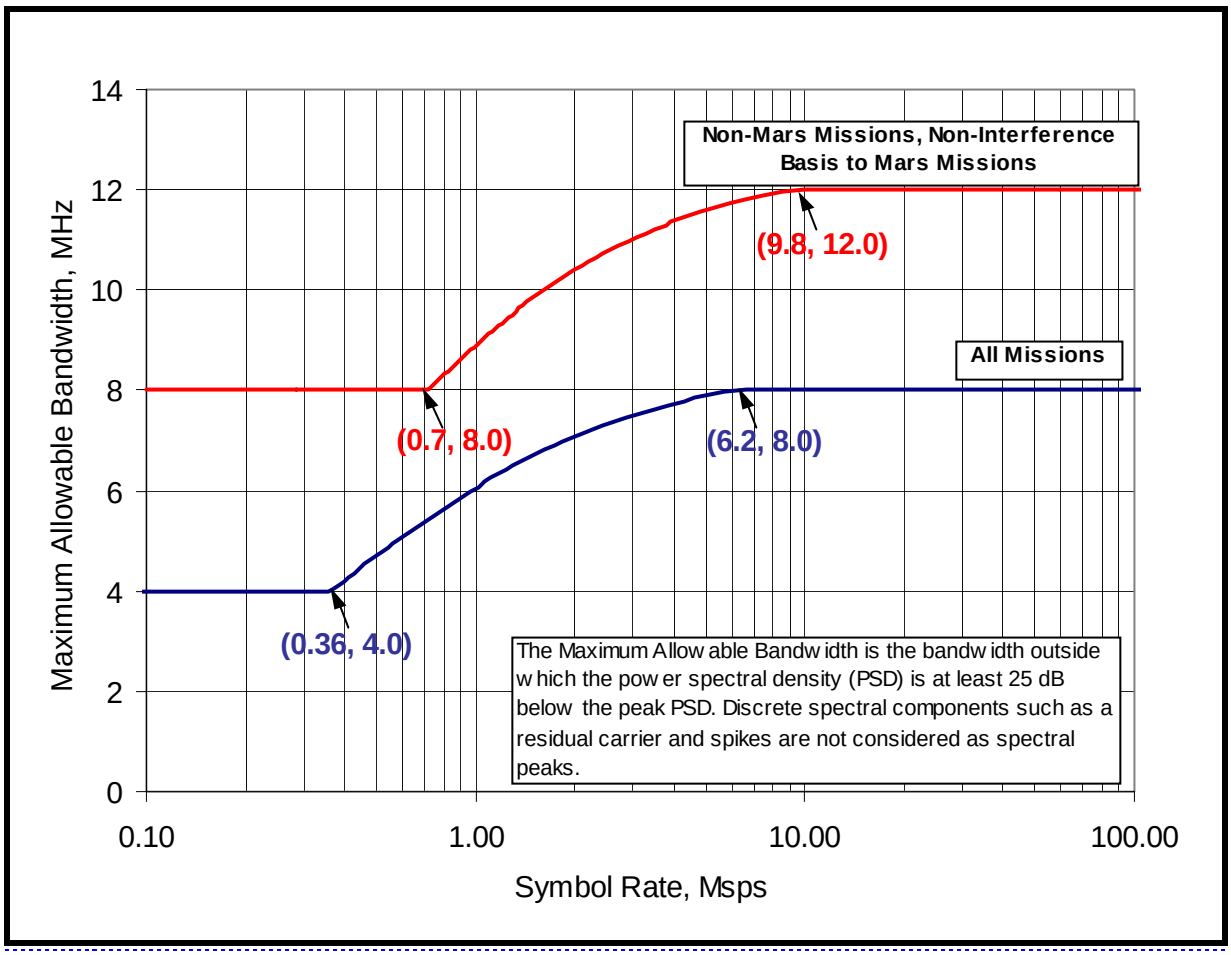

Figure 3.1.2B-1: Maximum Allowable Bandwidth (B25) vs. Symbol Rate (R_s)

NOTE – In the transition regions, B25 in MHz=k*R_s/(0.41+R_s) where k=8.53 and 12.5 for All Missions and Non–Mars Missions, respectively.

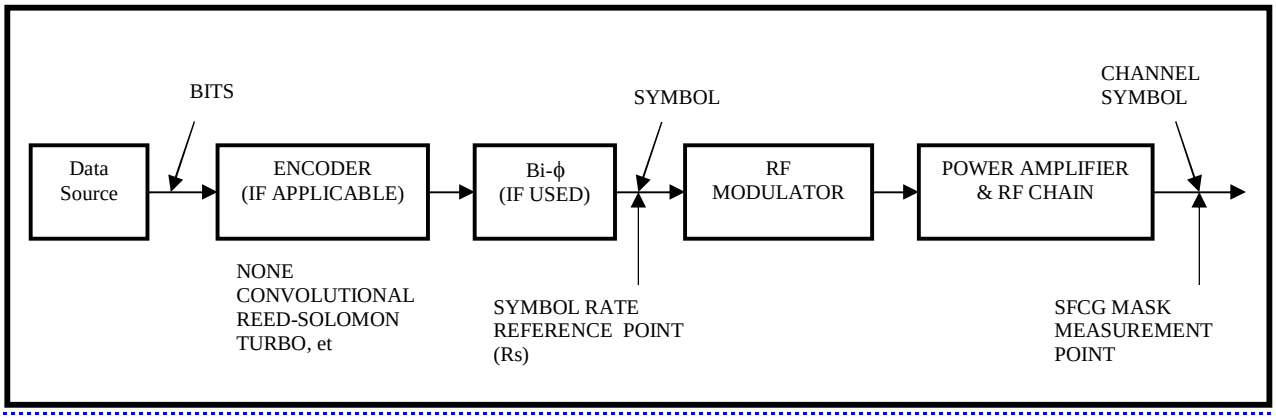

Figure 3.1.2B-2: Symbol Rate Definition

3.3.3A ~~CRITERIA FOR USE OF QPSK~~ PREFERRED MODULATION ~~IN~~ FORMATS FOR SUPPRESSED CARRIER SYSTEMS, CATEGORY A

The CCSDS,

considering

(a) that efficient use of RF spectrum resources is becoming increasingly important;

(b) that suppressed carrier systems are more bandwidth and power efficient than are residual carrier systems and OQPSK/QPSK modulations are more bandwidth efficient than BPSK;

(c) that in a realistic channel OQPSK systems are less sensitive to non-linear channel effects than are ~~standard~~ QPSK systems;

(d) that sync word detection hardware for phase ambiguity resolution is simpler in a OQPSK system than is the case with a ~~standard~~ QPSK system;

(e) that ~~standard~~ QPSK and OQPSK systems are widely used modulation techniques in bandwidth limited systems;

(f) that Recommendation 2.4.17A defines recommended bandwidth-efficient modulation formats for high symbol rate (> 2 Msps) space-to-Earth transmissions from Category A missions in space research service bands;

recommends

(1) that OQPSK ~~or standard QPSK~~ modulation[1] ~~be used~~is preferred in communications systems operating at frequencies where the available bandwidth is limited (e.g., in the 2 and 8 GHz bands) for medium-rate symbol transmissions (≤ 2 Msps);

(2) that CCSDS agencies refer to Recommendations 2.4.17A for recommended modulation formats for high symbol rate (> 2 Msps) transmissions.

[1] Subject to the constraints of SFCG recommendations 21-2R1 or latest version.